DECLARATION

I, the undersigned, of 2-12, Nakazaki 2-chome, Kita-ku, Osaka, Japan, hereby certify that I am well acquainted with the English and Japanese languages, that I am an experienced translator for patent matter, and that the attached document is a true English translation of

Japanese Patent Application No. **9-189841**

that was filed in Japanese.

I declare that all statements made herein of may own knowledge are true, that all statements on information and belief are believed to be true, and that these statements were made with the knowledge that willful statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Signature:

Y. Iwasaka

Yoshiharu Iwasaka

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(Translation)

[Name of the Document] SPECIFICATION

[Title of the Invention] Optical evaluation apparatus and optical evaluation method

[Claims]

[Claim 1] An optical evaluation method for evaluating electrical properties of an insulating film formed on a semiconductor region of a substrate, characterized by comprising:

a first step of making exciting light be transmitted through the insulating film and be intermittently irradiated onto the semiconductor region immediately under it;

a second step of making measurement light be transmitted through the insulating film and be irradiated onto the semiconductor region which is intermittently irradiated with the exciting light;

a third step of calculating a variation amount of a reflectivity of the measurement light by dividing a difference between the reflectivity of the measurement light when the exciting light is irradiated onto the semiconductor region and the reflectivity thereof when the exciting light is not irradiated thereon by the reflectivity thereof when the exciting light is not irradiated thereon; and

a fourth step of determining the insulating film to be a good product if the variation amount calculated in the step is within a predetermined range and determining the insulating

film to be defective if an absolute value of the variation amount is out of the predetermined range.

[Claim 2] The optical evaluation method of Claim 1,

characterized in that the semiconductor region is made of n-type silicon single crystals.

[Claim 3] The optical evaluation method of Claim 1 or 2,

characterized in that the insulating film is constituted by a silicon oxide film.

[Claim 4] The optical evaluation method of one of Claims 1 to 3,

characterized in that, in the fourth step, the insulating film is determined to be good or bad, depending upon whether or not the variation amount of the reflectivity of the measurement light is within the predetermined range at a particular energy value of the measurement light providing an extremum in a spectrum of the variation amount of the reflectivity of the measurement light.

[Claim 5] The optical evaluation method of Claim 4,

characterized in that the particular energy value of the measurement light is any value included within the range of 3.2 to 3.6 eV.

[Claim 6] The optical evaluation method of one of Claims 1 to 5,

characterized in that a wavelength range of the measurement light irradiated onto the semiconductor region is equal to or lower than 600 nm.

[Claim 7] The optical evaluation method of one of Claims 1 to 6,

characterized in that basic components of ellipsometric spectroscopy are used.

[Claim 8] The optical evaluation method of one of Claims 1 to 7,

characterized in that the respective steps are performed with a semiconductor device housed within a chamber, in which a gate oxide film is formed, after a step of forming the gate oxide film has been completed in a fabrication process of the semiconductor device.

[Claim 9] An optical evaluation apparatus for evaluating electrical properties of an insulating film formed on a semiconductor region of a substrate, characterized by comprising:

a first light source for generating exciting light;

a second light source for generating measurement light;

a first light guiding member configured so as to make the exciting light, generated by the first light source, be transmitted through the insulating film and be intermittently irradiated onto the semiconductor region immediately under it;

a second light guiding member configured so as to make the measurement light, generated by the second light source, be transmitted through the insulating film and be irradiated onto the semiconductor region which is intermittently irradiated with the exciting light;

reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor region;

a third light guiding member configured so as to make the measurement light, reflected by the semiconductor region, incident onto the reflectivity detection means;

variation calculation means for receiving an output of the reflectivity detection means and calculating a variation amount of the reflectivity of the measurement light by dividing a difference between the reflectivity of the measurement light when the exciting light is irradiated onto the semiconductor region and the reflectivity thereof when the exciting light is not irradiated thereon by the reflectivity thereof when the exciting light is not irradiated thereon; and

evaluation means for evaluating the electrical properties of the insulating film based on a magnitude of the variation amount of the reflectivity of the measurement light.

[Claim 10] The optical evaluation apparatus of Claim 9,

characterized in that the evaluation means determines it to be a good product only when the variation amount of the reflectivity of the measurement light is within the predetermined range at a particular energy value of the measurement light providing an extremum in a spectrum of the variation amount of the reflectivity of the measurement light.

[Claim 11] The optical evaluation apparatus of Claim 10,

characterized in that the particular energy value of the measurement light is any value included within the range of 3.2 to 3.6 eV.

[Claim 12] The optical evaluation apparatus of one of Claims 9 to 11,

characterized by further comprising spectroscope means for receiving the measurement light reflected by the semiconductor region, separating the measurement light and then providing it to the reflectivity detection means.

[Claim 13] The optical evaluation apparatus of one of Claims 9 to 11,

characterized by further comprising a filter for receiving the measurement light reflected by the semiconductor region, transmitting only a component of the measurement light within a wavelength range corresponding to the particular energy value of the measurement light, and then providing it to the reflectivity detection means.

[Claim 14] The optical evaluation apparatus of Claim 9,

characterized in that the wavelength range of the measurement light irradiated onto the semiconductor region is equal to or lower than 600 nm.

[Claim 15] The optical evaluation apparatus of one of Claims 9 to 14,

characterized by being configured by using an ellipsometric spectroscope.

[Claim 16] The optical evaluation apparatus of one of Claims 9 to 15,

characterized by being attached to a chamber used for forming an oxide film of a semiconductor device.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to an optical evaluation apparatus and an optical evaluation method for a semiconductor device, and more particularly relates to a control of the properties of an insulating film during the fabrication process.

[0002]

[Prior Art]

In recent years, semiconductor integrated circuits have achieved a remarkably high degree of integration. Thus, in a MOS device for constituting a semiconductor integrated circuit, efforts have also been made in order to develop a device such as a transistor having an even smaller size and an even higher performance. Now that a transistor or the like of such a very small size and such a high performance has been provided, it is necessary to improve the reliability of the MOS device. In addition, in order to improve the reliability of a MOS device, each portion constituting the MOS device is required to have high reliability.

[0003]

As for a gate insulating film, in particular, used for a MOS device, the film thickness thereof has been rapidly reduced. Thus, a very thin insulating film of 4 nm or less is expected to be used in the 21st century. In a MOS device having such an extremely thin insulating film, the properties of the insulating film are thought so much of as to be said to determine the characteristics of the entire MOS device and thus the electrical characteristics of the whole semiconductor integrated circuit. Therefore, the properties of the insulating film are considered particularly important.

[0004]

The properties of such a gate insulating film have conventionally been controlled by forming a MOS capacitor or a MOS transistor and evaluating the electrical characteristics thereof. Such an evaluation of the electrical characteristics is performed during or after the fabrication of a MOS device by taking out a wafer with the MOS device mounted thereon from a chamber.

[0005]

[Problems to be Solved by the Invention]

However, in the case of controlling the properties of the gate insulating film in the above-described manner by evaluating the electrical characteristics as has conventionally been done, even when any defect is generated in the process of forming the insulating film during the fabrication of the MOS

device, the defect is not found out until the wafer is taken out from the chamber and then the electrical characteristics thereof are evaluated after the process has been completed. Thus, the gate insulating film having such a defect is continuously formed until then. As a result, the productivity (efficiency) is decreased.

[0006]

In view of these respects, the present invention has been devised and the objective thereof is providing an optical evaluation apparatus and an optical evaluation method which can control in-line various properties of an insulating film during the fabrication process of the insulating film by taking every means for optically evaluating the properties, the electrical properties in particular, of the insulating film during the process step of forming the insulating film.

[0007]

[Means for Solving the Problems]

In order to accomplish the above-described objective, the present invention takes various means regarding the optical evaluation method which are recited in Claims 1 to 8 and various means regarding the optical evaluation apparatus which are recited in Claims 9 to 16.

[0008]

As recited in Claim 1, the optical evaluation method of the present invention is an optical evaluation method for evaluating electrical properties of an insulating film formed on a

semiconductor region of a substrate, and includes: a first step of making exciting light be transmitted through the insulating film and be intermittently irradiated onto the semiconductor region immediately under it; a second step of making measurement light be transmitted through the insulating film and be irradiated onto the semiconductor region which is intermittently irradiated with the exciting light; a third step of calculating a variation amount of a reflectivity of the measurement light by dividing a difference between the reflectivity of the measurement light when the exciting light is irradiated onto the semiconductor region and the reflectivity thereof when the exciting light is not irradiated thereon by the reflectivity thereof when the exciting light is not irradiated thereon; and a fourth step of determining the insulating film to be a good product if the variation amount calculated in the step is within a predetermined range and determining the insulating film to be defective if an absolute value of the variation amount is out of the predetermined range.

[0009]

Information about the electrical defects of an insulating film, those in a gate insulating film in particular, can be obtained by this method. Specifically, when exciting light is irradiated onto a semiconductor region, carriers are excited. And the electric field is varied in accordance with the variation in numbers of carriers. Thus, the reflectivity of the measurement light from the semiconductor region is varied in a

wavelength range. In such a case, if an insulating film has been formed on the semiconductor region, then a defect layer, to be a trap of the carriers, exists in the surface layer of the semiconductor region. As a result, the variation amount of the reflectivity of the measurement light is decreased. However, if the number of defects (trapped electrons) in the insulating film is large, then the increment of the electric field in the adjacent semiconductor region becomes large. As a result, the variation amount of the reflectivity of the measurement light is also increased. Thus, by determining the insulating film to be defective when the variation amount of the reflectivity of the measurement light is large, the electrical properties of the insulating film can be determined to be good or bad rapidly and exactly.

[0010]

As recited in Claim 2, the semiconductor region of Claim 1 is preferably made of n-type silicon single crystals.

[0011]

As recited in Claim 3, the insulating film of Claim 1 or 2 is preferably constituted by a silicon oxide film.

[0012]

As recited in Claim 4, in the fourth step, the insulating film is preferably determined to be good or bad in one of Claim 1 to 3, depending upon whether or not the variation amount of the reflectivity of the measurement light is within the predetermined range at a particular energy value of the measurement

light providing an extremum in a spectrum of the variation amount of the reflectivity of the measurement light.

[0013]

As recited in Claim 5, the particular energy value of the measurement light of Claim 4 is preferably any value included within the range of 3.2 to 3.6 eV.

[0014]

In accordance with the method of Claim 4 or 5, the optical evaluation is performed at a point in the spectrum of the variation amount of the reflectivity showing a characteristic shape, in which point the sensitivity for detecting the difference in electrical properties of the insulating film is best.

[0015]

As recited in Claim 6, a wavelength range of the measurement light irradiated onto the semiconductor region is preferably equal to or lower than 600 nm in one of Claims 1 to 5.

[0016]

In accordance with this method, the optical evaluation is performed based on the variation amount of the reflectivity of only a part of the semiconductor region which is affected by the trapped electrons in the insulating film, by utilizing the fact that the measurement light in a wavelength range equal to or lower than the visible light region, in particular, does not reach a depth of more than several tens nm in the semiconductor region.

[0017]

As recited in Claim 7, basic components of ellipsometric spectroscopy may be used in one of Claims 1 to 6。

[0018]

In accordance with this method, the measurement light generation source, the spectroscope system, the light intensity detector and the like, which are provided for an ellipsometric spectroscope, can be directly used。 Thus, the costs of the entire apparatus required for performing this optical evaluation method can be reduced。

[0019]

As recited in Claim 8, the respective steps are preferably performed in one of Claims 1 to 7 with a semiconductor device housed within a chamber, in which a gate oxide film is formed, after a step of forming the gate oxide film has been completed in a fabrication process of the semiconductor device。

[0020]

In accordance with this method, the electrical properties of the insulating film can be monitored in-line, while continuously processing a semiconductor wafer in a chamber。

[0021]

As recited in Claim 9, the optical evaluation apparatus of the present invention is an optical evaluation apparatus for evaluating electrical properties of an insulating film formed on a semiconductor region of a substrate, and includes: a first light source for generating exciting light; a second light

source for generating measurement light; a first light guiding member configured so as to make the exciting light, generated by the first light source, be transmitted through the insulating film and be intermittently irradiated onto the semiconductor region immediately under it; a second light guiding member configured so as to make the measurement light, generated by the second light source, be transmitted through the insulating film which is intermittently irradiated with the exciting light and be irradiated onto the semiconductor region immediately under it; reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor region; a third light guiding member configured so as to make the measurement light, reflected by the semiconductor region, incident onto the reflectivity detection means; variation calculation means for receiving an output of the reflectivity detection means and calculating a variation amount of the reflectivity of the measurement light by dividing a difference between the reflectivity of the measurement light when the exciting light is irradiated onto the semiconductor region and the reflectivity thereof when the exciting light is not irradiated thereon by the reflectivity thereof when the exciting light is not irradiated thereon; and evaluation means for evaluating the electrical properties of the insulating film based on a magnitude of the variation amount of the reflectivity of the measurement light.

[0022]

This makes it possible to obtain information about the electrical defects of an insulating film, those of a gate insulating film in particular. Specifically, when exciting light is irradiated onto a semiconductor region, carriers are excited. And the electric field is varied in accordance with the variation in numbers of the carriers. Thus, the reflectivity of the measurement light from the semiconductor region is varied in a wavelength range. In such a case, if an insulating film has been formed on the semiconductor region, then a defect layer, to be a trap of the carriers, exists in the surface layer of the semiconductor region. As a result, the variation amount of the reflectivity of the measurement light is decreased. However, if the number of defects (trapped electrons) in the insulating film is large, then the increment of the electric field in the adjacent semiconductor region becomes large. As a result, the variation amount of the reflectivity of the measurement light is also increased. Thus, by making the evaluation means determine it to be defective when the reflectivity of the measurement light is out of the predetermined range, the electrical properties of the insulating film can be controlled rapidly and exactly.

[0023]

As recited in Claim 10, the evaluation means of Claim 9 preferably determines it to be a good product only when the variation amount of the reflectivity of the measurement light is within the predetermined range at a particular energy value

of the measurement light providing an extremum in a spectrum of the variation amount of the reflectivity of the measurement light.

[0024]

As recited in Claim 11, the particular energy value of the measurement light of Claim 10 is any value included within the range of 3.2 to 3.6 eV.

[0025]

In accordance with Claim 10 or 11, the optical evaluation is performed at a point in the spectrum of the variation amount of the reflectivity showing a characteristic shape, in which point the sensitivity for detecting the difference in electrical properties of the insulating film is best.

[0026]

As recited in Claim 12, spectroscope means for receiving the measurement light reflected by the semiconductor region, separating the measurement light and then providing it to the reflectivity detection means may be further provided in any one of Claims 9 to 11.

[0027]

This makes it possible to perform a high-precision optical evaluation based on the entire shape of the spectrum, because the spectrum of the variation amount of the reflectivity of the measurement light is detected.

[0028]

As recited in Claim 13, a filter for receiving the measurement light reflected by the semiconductor region, transmitting only a component of the measurement light within a particular wavelength range and providing it to the reflectivity detection means may be further provided in any one of Claims 9 to 11.

[0029]

This makes it possible to simplify the structure of an optical evaluation apparatus and to perform an optical evaluation rapidly, because the variation in reflectivity within a desired wavelength range can be detected without providing spectroscope means.

[0030]

As recited in Claim 14, the wavelength range of the measurement light irradiated onto the semiconductor region is preferably equal to or lower than 600 nm in any one of Claims 9 to 13.

[0031]

This makes it possible to perform the optical evaluation based on the variation amount of the reflectivity of only a part of the semiconductor region which is affected by the trapped electrons in the insulating film, by utilizing the fact that the measurement light in a wavelength range equal to or lower than the visible light region, in particular, does not reach a depth of more than several hundreds nm in the semiconductor region.

[0032]

As recited in Claim 15, it may be configured by using an ellipsometric spectroscope in any one of Claims 9 to 14.

[0033]

This makes it possible to constitute an optical evaluation apparatus with lower costs by using an ellipsometric spectroscope used for measuring the film thickness of a gate oxide film and the like during the fabrication process of a semiconductor device.

[0034]

As recited in Claim 16, the optical evaluation apparatus of any one of Claims 9 to 15 is preferably attached to a chamber used for forming an oxide film of a semiconductor device.

[0035]

As a result, since the quality of an insulating film can be evaluated without taking a semiconductor substrate out of a fabrication apparatus, it becomes an evaluation apparatus suitable for in-line characteristic evaluation.

[0036]

[Embodiments of the Invention]

Hereinafter, the optical evaluation apparatus and the optical evaluation method for a semiconductor device (insulating film) according to an embodiment of the present invention will be described with reference to Figures 1 to 6.

[0037]

Figure 1 is a perspective view schematically showing the configuration of the optical evaluation apparatus for an insulating film in this embodiment. In Figure 1, 101 denotes a semiconductor substrate in the form of wafer on which a silicon oxide film has been formed; 102 denotes a wafer stage; 103 denotes a Xe lamp, as a second light source, having an output of 150 W; 104 denotes a polarizer; 105 denotes a detector having a photodetector; 106 denotes probe light (measurement light) which is the light of the Xe lamp; 107 denotes reflected probe light; 108 denotes a signal line for transmitting a signal from the detector 105 therethrough; 109 denotes an Ar ion laser, as a first light source, having an output of 5 W; 110 denotes a chopper for modulating the exciting light; 111 denotes exciting light which is the exciting light modulated by the chopper 110; 112 denotes a signal line for transmitting a signal in synchronism with the modulation of the exciting light; and 113 denotes a control system. And the detector 105 is configured so as to measure the intensity of the reflected probe light 107 as a continuous spectrum for each wavelength. Also, the exciting light 111 is formed so as to be chopped by the chopper 110 at a frequency of 500 Hz and be intermittently irradiated onto the region to be measured on the semiconductor substrate 101 from a direction vertical to the surface of the semiconductor substrate 101. Furthermore, the chopper 110 and the detector 105 for detecting the intensity of the reflected light are configured so as to operate in synchronism with each other.

[0038]

On the other hand, as shown in Figure 2, a silicon oxide film **101c** has been formed by a thermal oxidation method at a temperature of 850℃ or lower, for example, on an n-type semiconductor region **101b** as the region to be measured in the semiconductor substrate **101**. The probe light **106** passes through the silicon oxide film **101c** to be incident onto the n-type semiconductor region **101b** immediately under it and then reflected by the surface of the n-type semiconductor region **101b**. And, the reflected probe light **107** passes through the silicon oxide film **101c** and emitted outward.

[0039]

In addition, though a chamber for performing thermal oxidization is not illustrated in Figure 1, the wafer stage **102** is disposed within the chamber. The chamber is provided with windows for passing the probe light **106**, the reflected probe light **107** and the exciting light **111**.

[0040]

Hereinafter, the fundamental principle of the optical-modulation reflectivity spectroscopy and a method for measuring the variation amount ($\Delta R/R$) in reflection intensity of the reflected probe light **107** according to this embodiment will be described.

[0041]

In general, when semiconductor is irradiated with light, carriers are excited by the light to increase the number thereof. Thereafter, when the carriers return to the original energy level, they are extinct while emitting light. A surface electric field in the semiconductor region is varied in accordance with such a variation in numbers of carriers. Thus, the ratio at which the measurement light is reflected by the surface of the semiconductor region, i.e., the reflectivity of the measurement light, when exciting light is irradiated is different from the reflectivity when exciting is not irradiated. That is to say, if the magnitude of the variation of the electric field to be generated upon the irradiation of the exciting light is varied depending upon any property of the region to be measured, then the properties of the region to be measured might be evaluated by measuring the variation amount of the reflectivity of the measurement light. The present invention supposes such optical-modulation reflectivity spectroscopy technologies as a premise.

[0042]

Thus, in this embodiment, the variation in reflection intensity of the reflected probe light **107** is detected by making the exciting light **111** pass through the silicon oxide film on the semiconductor substrate **101** as the region to be measured so as to intermittently irradiate it onto the n-type semiconductor region immediately under it and by simultaneously making the probe light **106** continuously pass through the silicon oxide

film from another direction so as to irradiate it onto the n-type semiconductor region immediately under it. And, the value ($\Delta R/R$) obtained by dividing the difference ΔR between the reflection intensity of the reflected probe light **107** when the exciting light **111** is irradiated and the reflection intensity thereof when it is not irradiated by the reflection intensity R when the exciting light **111** is not irradiated is detected by an analysis system **113** as a variation amount of the reflection intensity. Herein, the variation amount ($\Delta R/R$) of reflection intensity is used instead of the reflectivity on the assumption that the intensity of the probe light **106** to be irradiated is constant. Thus, it is the variation amount of the reflectivity that has technological significance. The variation in variation amount of the reflection intensity of the probe light is monitored by the above-described configuration. And, on the display of the analysis system **113** shown in Figure **1**, the spectrum of the variation amount ($\Delta R/R$) of the reflection intensity of the measurement light, such as the illustrated one, is displayed.

[0043]

Figure **3** shows the spectrum of the variation amount ($\Delta R/R$) of the reflection intensity measured by the detector **105**. In this figure, the curve **Spa** represents the spectrum of the variation amount ($\Delta R/R$) of reflection intensity from the semiconductor substrate having a normal silicon oxide film and the

curves Spb and Spc represent respective spectra of the variation amounts (Δ R/R) of reflection intensities from semiconductor substrates having defective silicon oxide films. From the difference in shapes of these spectra of the variation amounts (Δ R/R) of reflection intensities, it was found that the variation amount (Δ R/R) of the reflection intensity for a good semiconductor substrate is included within a certain range (the hatched region in this figure), while the magnitudes of the variation amounts (Δ R/R) of reflection intensities for defective semiconductor substrates are too large to be included within this range. Such a difference is presumably caused because of the following action.

[0044]

As shown in Figure 4(a), when the exciting light (exciting light) 111 is passed through the silicon oxide film and irradiated onto the n-type semiconductor region immediately under it, carriers are generated in the n-type semiconductor region and the surface electric field is intensified by $\Delta \phi$ in accordance with the variation in numbers of carriers. It has already been described that the reflection intensity when the exciting light is irradiated differs from that when it is not irradiated because of the generation of the variation $\Delta \phi$ of the surface electric field. Herein, if the silicon oxide film has been formed on the n-type semiconductor region, then a defect layer for trapping the carriers is formed in the surface layer of the

n-type semiconductor region. Accordingly, the variation of the reflectivity of the measurement light might be decreased.

[0045]

However, if trapped electrons exist in the silicon oxide film as shown in Figure 4(b), then a larger variation $\Delta \phi'$ of the surface electric field is caused by these electrons in the n-type semiconductor region. Thus, the variation amount ($\Delta R/R$) of the reflection intensity from the n-type semiconductor region immediately under the silicon oxide film, in which a large number of trapped electrons exist, is considered to be larger than the variation amount ($\Delta R/R$) of the reflection intensity from the n-type semiconductor region immediately under the silicon oxide film in which a small number of trapped electrons exist. That is to say, a large number of trapped electrons exist in the silicon oxide films on the semiconductor substrates providing the spectra Spb and Spc having large variation amounts ($\Delta R/R$) of the reflection intensities such as those shown in Figure 3. It is known that the larger number of such trapped electrons exist, the larger the number of defects in the silicon oxide film is. It is also known that if a large number of trapped electrons exist, then a carrier path resulting from dielectric breakdown is more likely to be formed and the longevity of an insulating film becomes short.

[0046]

Thus, in order to support the above-described supposition, the present inventors conducted experiments in which electric stress is applied to a silicon oxide film having a thickness of about 2 to 4 nm, so as to have the magnitude thereof set at various values, thereby obtaining data shown in Figure 5. Figure 5 is a diagram showing the relationship between the peak intensity in the spectrum of the variation amount (ΔR/R) of reflection intensity and the density of trapped electrons in each of the oxide films obtained by capacitance measurement. In this figure, the axis of ordinates indicates the densities of trapped electrons ($\times 10^{11}$ cm^2) and the axis of abscissas indicates the relative values of peak signal intensities providing a relative minimum value (corresponding to a wavelength around 375 nm) in the vicinity of 3.35 eV in the spectrum of the variation amount (ΔR/R) of reflection intensity. As shown in Figure 5, the density of trapped electrons becomes higher as the absolute value of the peak signal intensity becomes higher. Thus, the quality of a silicon oxide film can be evaluated not good (i.e., in which a larger number of trapped electrons exist) when the absolute value of the variation amount (ΔR/R) of reflection intensity exceeds a certain range.

[0047]

That is to say, if the variation amount (ΔR/R) (absolute value) of reflection intensity is equal to or larger than a

predetermined value, then determining the gate oxide film to be defective is consistent with the empirically obtained relation of cause and effect, whether the above-described supposition is theoretically true or not. Therefore, since the quantity of trapped electrons in the insulating film can be specified by monitoring the variation amount ($\Delta \mathbb{R}/\mathbb{R}$) of reflection intensity, the control of the electrical properties of the film can be performed optically.

[0048]

Next, an example in which the process control is performed in accordance with such optical evaluation during the fabrication of a semiconductor device will be described.

[0049]

As shown in Figure 6, process control was performed in modeling a silicon oxide film on a semiconductor substrate (wafer) by thermal oxidation while determining it to be good if the peak value in the spectrum of the variation amount ($\Delta \mathbb{R}/\mathbb{R}$) of reflection intensity is within a range of -0.25×10^{-3} to 0.25×10^{-3} and to be defective if it is out of the range. In Figure 6, the axis of abscissas indicates the number of processed wafers and the axis of ordinates indicates (the peak value of) the variation amount ($\Delta \mathbb{R}/\mathbb{R}$) of reflection intensity in the vicinity of 3.35 eV. As a result of monitoring performed once per 125 wafers, a signal suddenly varied abruptly when the 750th wafer was monitored, which was an unexpected trouble.

The properties of the gate oxide film at such a time were represented by a time tbd (longevity value) of about 100 sec. indicating the reliability thereof, i.e., a time elapsed until the breakdown is generated when the voltage Vg applied to the gate is -6.6 V. Since a normal longevity value tbd is 10^4 sec. or more, it can be seen that this longevity value is abnormally low. In this case, the cause of trouble could be eliminated by prompt troubleshooting and the occurrence of defects could be prevented from then on. By controlling the fabrication process in accordance with the evaluation of optical properties in such a manner, the present invention can perform prompter troubleshooting than a conventional control in accordance with the evaluation of electrical characteristics. Consequently, in modeling a sample and in a fabrication process of a MOS device, the degradation of yield can be prevented with certainty.

[0050]

(Modified Embodiment of the Embodiment)

Figure 7 shows an optical monitoring system according to a modified embodiment of the above-described embodiment. As shown in this figure, a Xe lamp 502 for generating measurement light to be irradiated onto the semiconductor substrate 101 is provided. The probe light 507 generated by the Xe lamp 502 is reflected by a mirror 506 and then provided to the n-type semiconductor region of the semiconductor substrate 101 placed on a wafer stage 504. Though not shown, the diameter of the probe

light **507** can be converged by a lens down to 50μmϕ. And, the reflected probe light **508** reflected by the n-type semiconductor region is passed through the mirror **506** so as to be provided to a microscope system **505** and then the intensity thereof is detected by a system for observation and analysis **509**. In this embodiment, the irradiation of the probe light **507** onto the region to be observed and the take-out of the reflected robe light **508** can be performed in a direction vertical to the surface of the sample by using the microscope system **505** and the mirror **506** in combination. It is noted that data about the reflection intensity measured by the system for observation and analysis **509** is transmitted to a process control system (not shown) via a signal line.

[0051]

In addition, an Ar ion laser **503** having an intensity of 5 W for generating exciting light to be irradiated onto the n-type semiconductor region is also provided. The exciting light **511** generated by the Ar ion laser **503** is chopped by a chopper **510** at a frequency of 100 Hz, for example, and intermittently irradiated onto the n-type semiconductor region of the semiconductor substrate. And, the value (ΔR/R) obtained by dividing the difference ΔR between the reflection intensity of the measurement light (probe light) when the exciting light **511** is irradiated and that when it is not irradiated by the reflection intensity R when the exciting light **511** is not irradiated

is detected by the system for observation and analysis **509** as a variation amount of reflection intensity, as described above. The variation in variation amount of the reflection intensity of the probe light (i.e., the variation amount of reflectivity) is monitored by the above-described configuration. Also, a reflected exciting light observation system **513** for detecting the intensity of the reflected exciting light **512** from the semiconductor region is further provided. Information about the intensity of the reflected exciting light **512** is transmitted to the system for observation and analysis **509** via a signal line. The chopper **510** and a detector for detecting the intensity of the reflected light are configured so as to operate in synchronism with each other.

[0052]

In the optical evaluation apparatus shown in Figure **1** or **7**, only the variation amount ($\Delta R/R$) of reflection intensity in the vicinity of 3.35 eV may be monitored by the detector **105** by providing a filter for transmitting only the light having a wavelength in the vicinity of 3.35 eV, for example, for the optical path in which the reflected probe light passes. For example, such a filter may be provided in front of the detector **105** shown in Figure **1**.

[0053]

Moreover, in the optical evaluation apparatus shown in Figure **1** or **7**, the measurement light in the wavelength range of

600 nm or less is preferably irradiated onto the semiconductor region by selecting an appropriate light source for the measurement light or by providing a filter therefor. Since the penetration depth of the light in such a wavelength range into the semiconductor region does not become equal to or exceed several tens nm, a highly sensitive optical evaluation can be performed based on the variation amount of the intensity of the reflected light from the surface region which is likely to be affected by the trapped electrons in an insulating film such as a silicon oxide film.

[0054]

In the optical evaluation apparatus shown in Figure 1, the members of an ellipsometric spectroscope, which is currently used for measuring the film thickness of an oxide film, are directly applicable to the Xe lamp **103**, the polarizer **104**, the detector **105** and the like. In such a case, if only an Ar ion laser **109**, a chopper **110** and a control system **113** are newly provided, the optical evaluation of the present invention can be performed. Also, such an ellipsometric spectroscope may be partially used for the optical evaluation apparatus shown in Figure **7**.

[0055]

[Effects of the Invention]

According to Claims 1 to 8, exciting light is intermittently irradiated from over an insulating film onto a semiconductor region, while measurement light is also irradi-

ated onto the region, thereby determining the electrical properties of the insulating film to be good or bad in accordance with the variation amount in reflectivity of the measurement light. Thus, it is possible to provide an optical evaluation method which can evaluate the electrical properties in-line by utilizing the fact that the surface electric field in the semiconductor region is varied depending upon the amount of defects, such as trapped electrons, in the insulating film.

[0056]

According to Claim 7, in particular, an optical evaluation can be performed with low costs by using an ellipsometric spectroscope which is universally used for measuring the film thickness of an insulating film.

[0057]

And, the optical evaluation method of Claims 1 to 8 can be carried out easily if the optical evaluation apparatus of Claims 9 to 16 is used.

[Brief Description of the Drawings]

[Figure 1]

A block diagram showing, partly in perspective, the configuration of an optical evaluation apparatus according to an embodiment.

[Figure 2]

A cross-sectional view showing a structure of an object to be measured which is used for performing an optical evaluation in the embodiment.

[Figure 3]

A signal spectrum diagram about a variation amount of reflection intensity of probe light from a semiconductor region.

[Figure 4]

Energy band diagrams for a silicon oxide film and the n-type semiconductor region.

[Figure 5]

A diagram showing the relationship between a peak intensity in the spectrum of the variation amount of reflection intensity of the probe light and the density of trapped electrons in the oxide film.

[Figure 6]

A diagram showing the relationship between the number of processed wafers and the variation amount of reflection intensity in the vicinity of 3.35 eV in the case where the optical evaluation is utilized for controlling an oxidization process of a sample in accordance with the present invention.

[Figure 7]

A block diagram showing, partly in perspective, the configuration of an optical evaluation apparatus according to a modified embodiment of the embodiment.

[Description of the Reference Numerals]

101 semiconductor substrate

101a body portion

101b n-type semiconductor region

101c silicon oxide film

102 wafer stage

103 Xe lamp (second light source)

104 polarizer

105 detector

106 probe light

107 reflected probe light

108 signal line

109 Ar ion laser (first light source)

110 chopper

111 exciting light

112 signal line

113 control/analysis system

502 Xe lamp (second light source)

503 Ar ion laser (first light source)

504 wafer stage

505 microscope system

506 mirror

507 probe light

508 reflected probe light

509 system for observation and analysis

510 chopper

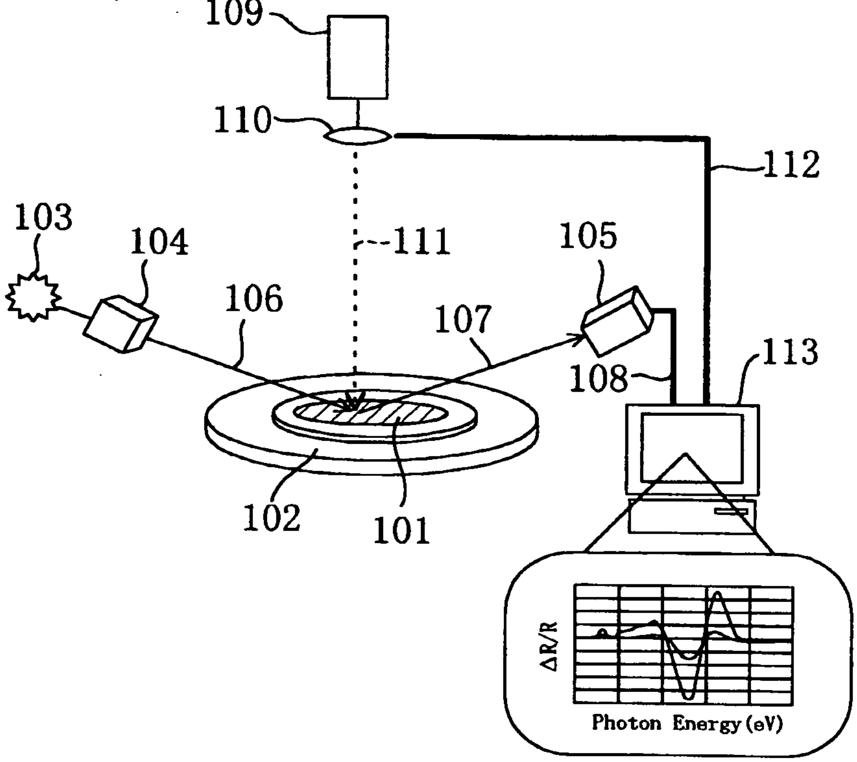
511 exciting light

512 reflected exciting light

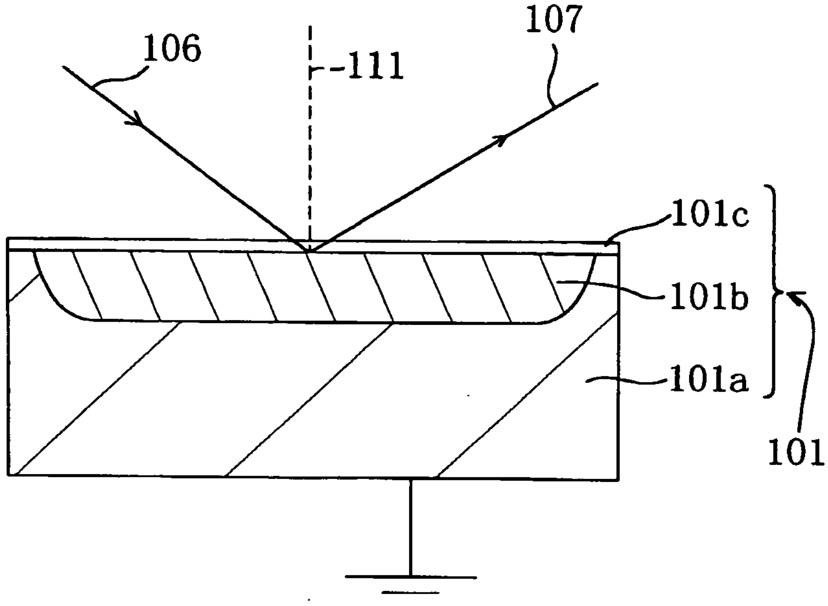
513 reflected exciting light observation system

【書類名】　図面
[Name of the Document] DRAWINGS

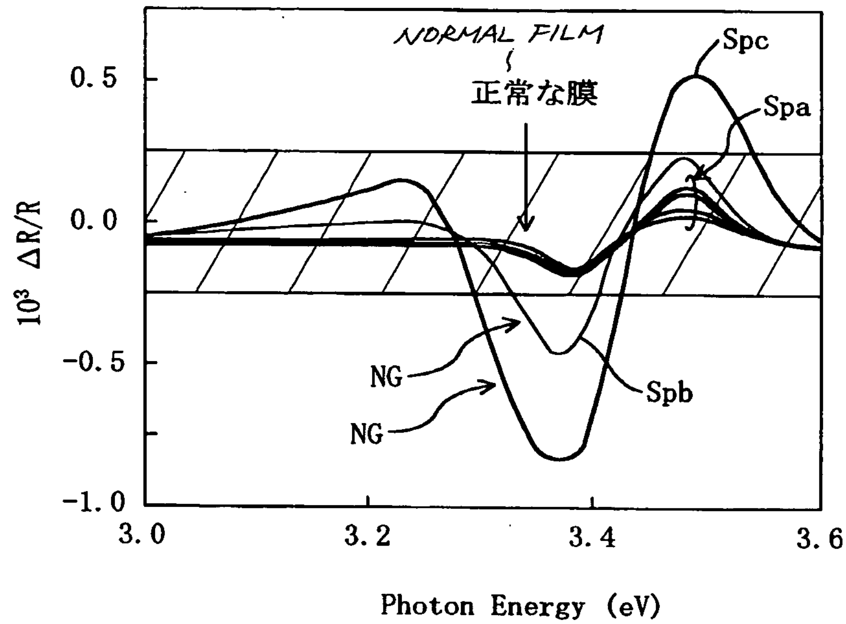
【図１】
[Figure 1]



【図２】
[Figure 2]

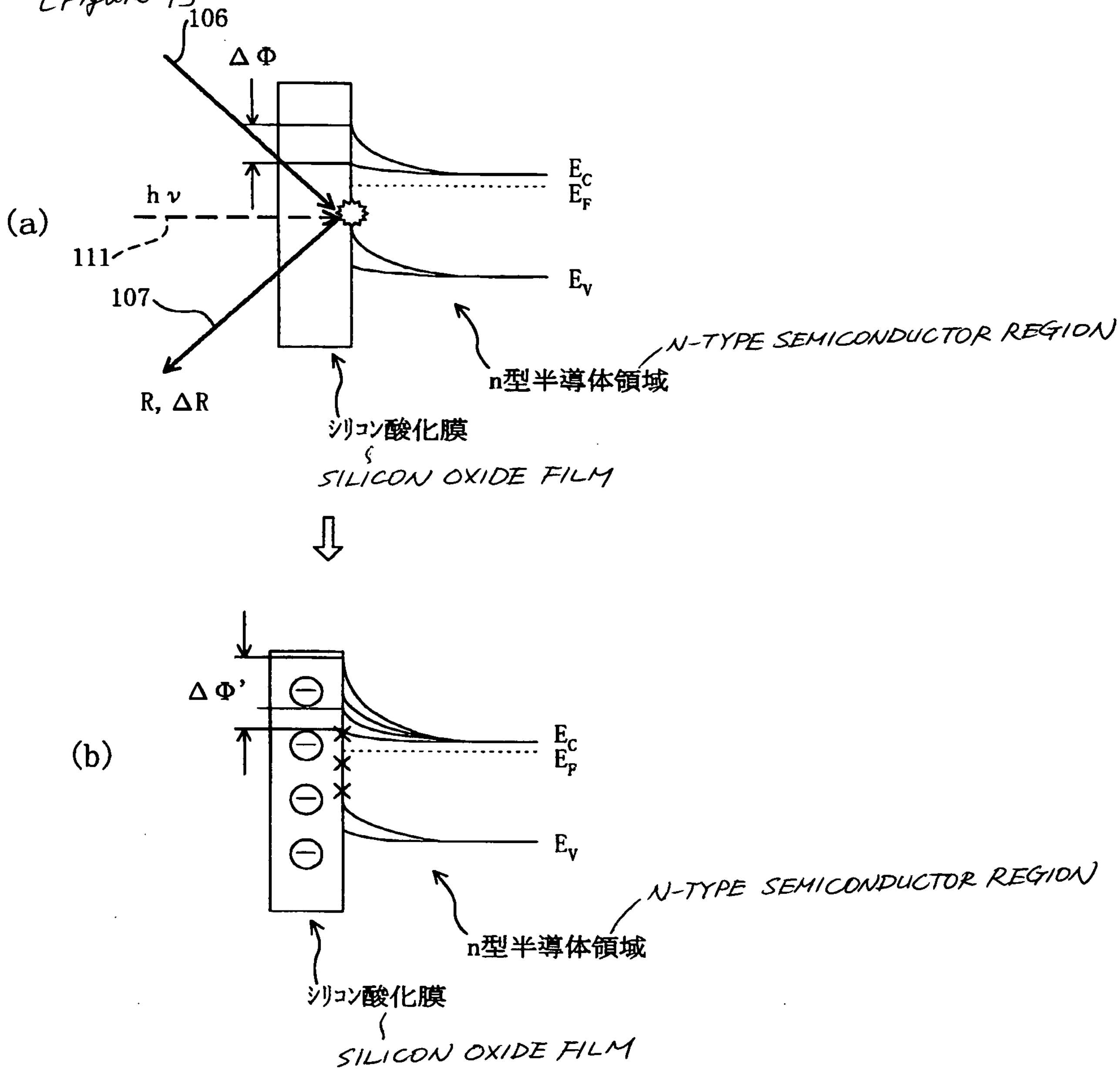


【図３】
[Figure 3]

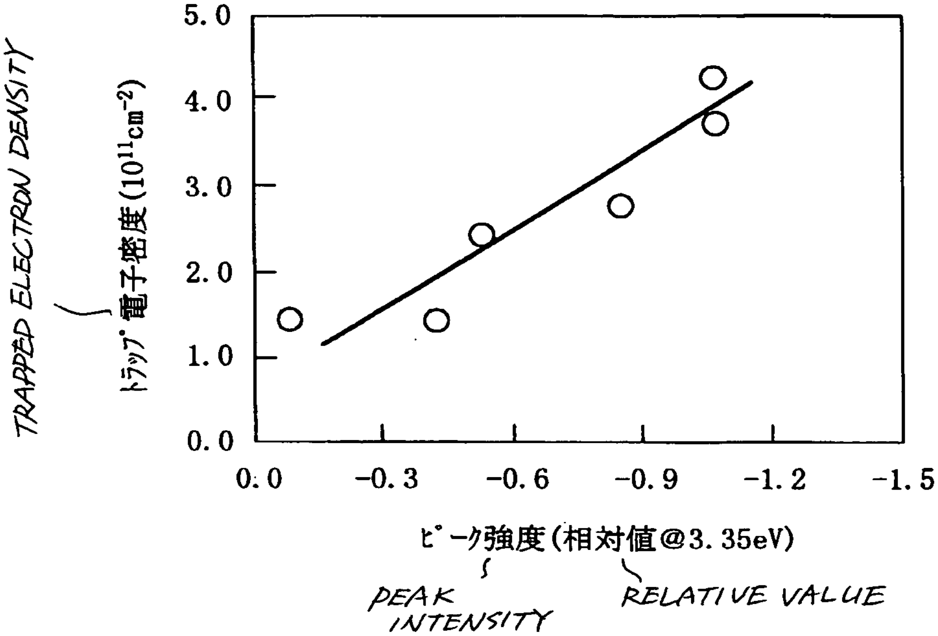

NORMAL FILM
正常な膜
Spc
Spa
Spb
NG
NG
0.5
0.0
-0.5
-1.0
10^3 ΔR/R
3.0
3.2
3.4
3.6
Photon Energy (eV)

【図４】

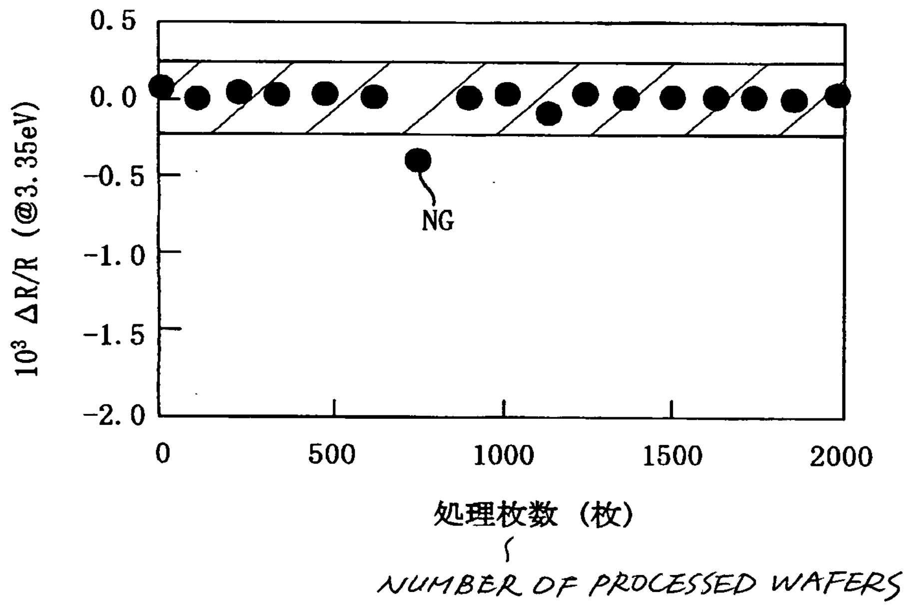
[Figure 4]


106
ΔΦ
E_C
E_F
hν
(a)
111
E_V
107
N-TYPE SEMICONDUCTOR REGION
n型半導体領域
R, ΔR
シリコン酸化膜
SILICON OXIDE FILM
ΔΦ'
E_C
E_F
(b)
E_V
N-TYPE SEMICONDUCTOR REGION
n型半導体領域
シリコン酸化膜
SILICON OXIDE FILM

【図５】
[Figure 5]

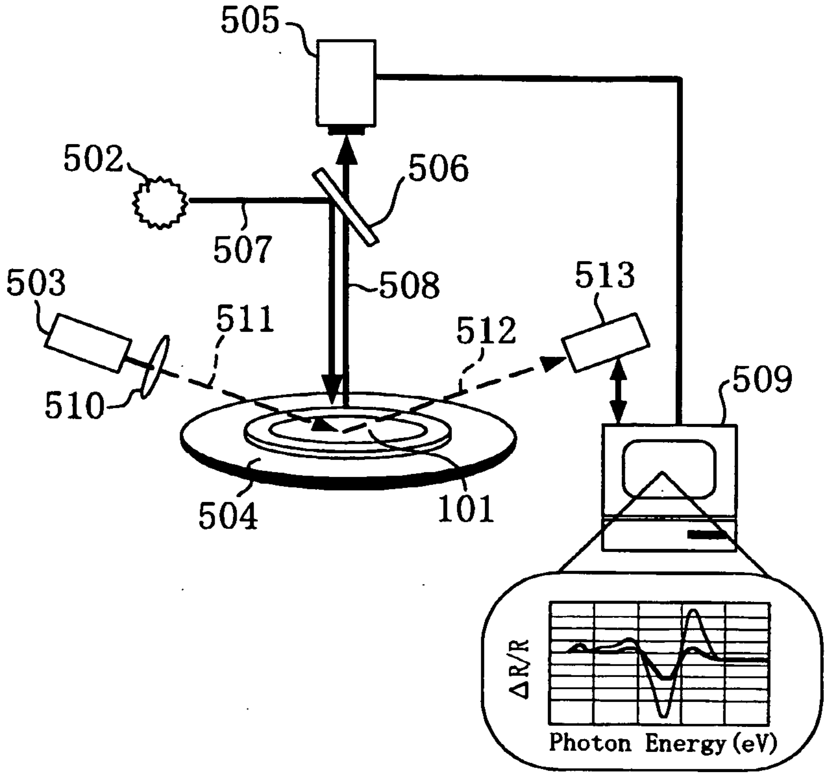


【図６】
[Figure 6]



【図７】

[Figure 7]


505
502
506
507
508
503
511
513
512
509
510
504
101
ΔR/R
Photon Energy (eV)

[Name of the Document] ABSTRACT

[Abstract]

[Problem] To provide an optical evaluation apparatus and an optical evaluation method enabling the in-line control of the electrical properties of an insulating film.

[Means for Solving the Problem] Exciting light from an Ar ion laser is passed through an insulating film and intermittently irradiated onto a semiconductor region immediately under it. Probe light (measurement light) from a Xe lamp is irradiated onto the region irradiated intermittently with the exciting light, and the intensity of the reflected light thereof is measured. In this case, the increment of the surface electric field in the semiconductor region when the exciting light is irradiated differs from that when it is not irradiated. Therefore, the reflectivity of the measurement light is particularly varied in a wavelength region. Then, if the number of defects (trapped electrons) in the insulating film is large, then the increment of the surface electric field in the semiconductor region is large. Thus, the variation amount of the reflectivity of the probe light is increased as compared with the case where the defects are few. Consequently, the insulating film is determined to be good when the variation amount of the reflectivity is within a predetermined range and to be defective when it exceeds the predetermined range.

[Selected Figure] Figure 3